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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04L 5/06	A1	(11) International Publication Number: WO 96/19056 (43) International Publication Date: 20 June 1996 (20.06.96)

(21) International Application Number: PCT/SE95/01413

(22) International Filing Date: 27 November 1995 (27.11.95)

(30) Priority Data:
9404356-9 14 December 1994 (14.12.94) SE

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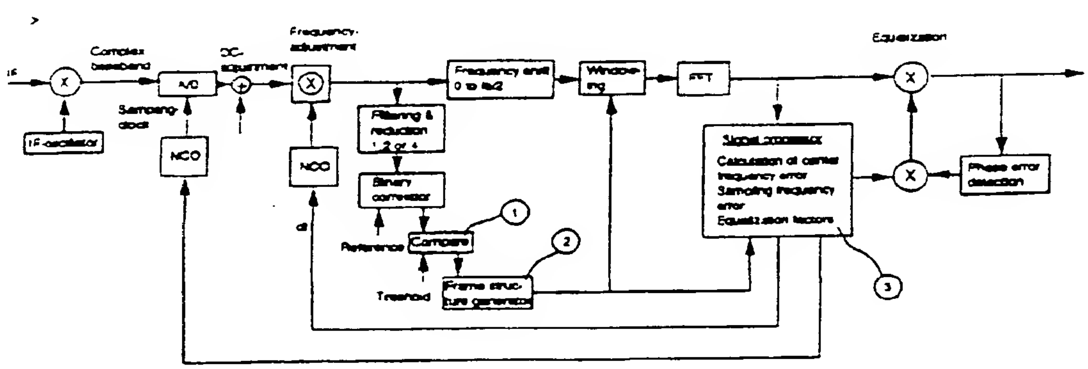
(81) Designated States: AU, BG, BR, BY, CA, CN, CZ, ES, FI, GE, HU, JP, KP, KR, LT, LV, MX, NO, NZ, PL, RO, RU, UA, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
With amended claims.

(54) Title: METHOD AT OFDM-RECEPTION FOR CORRECTION OF FREQUENCY, TIME WINDOW, SAMPLING CLOCK AND SLOW PHASE VARIATIONS



(57) Abstract

The present invention relates to a method for correction of frequency, time window error, sampling clock and phase error at OFDM-receivers. The information which is transmitted in a signal which includes several carriers in digital form, includes consecutive frames comprising a number of symbols. In respective frames at least one up-chirp and one down-chirp is arranged. Correction of the frequency is made based on analysis of the up- and down-chirps. Further the main focus of the weighted impulse response is determined. The position of the main focus is used for correction of the time window and the sampling clock. Further the vectors from the location of the received carriers are registred in relation to their ideal location in a matrix. The angles between the received vector and the ideally located vector are determined and are weighed together with regard to the amplitude of the transmission function at the frequency of the carrier and the distance of the vector to the origin of coordinates. An average is after that made of the weighed angle distances. The obtained average is used for correction of the phase error. Further, the knowledge of the obtained phase error and previous phase errors is used for estimation of the coming phase error in the following reception.

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TITLE OF THE INVENTION

Method at OFDM-reception for correction of frequency, time window, sampling clock and slow phase variations.

TECHNICAL FIELD

The present invention relates to a method at digital system for correction of frequency, sampling clock and phase error which varies slowly with time, i.e. low-frequency phase noise. The receiver is a so called OFDM-receiver which receives digital information in frames.

PRIOR ART

OFDM (Orthogonal Frequency Division Multiplex) is a type of modulation where a digital signal is multiplexed on many narrow-band carriers. The narrow-band carriers are packed with high density because one utilizes the fact that the carriers are orthogonal when the carrier separation is equal to 1 divided by the symbol lenght for rectangular symbols. The implementation of OFDM is usually made by means of special circuits which perform FFT (Fast Fourier Transform). At OFDM-signalling, channel coding and so called soft decoding (for instance Viterbi-decoding) is usually used in order to reduce the probability of error and make it possible to deal with frequency selective fading. OFDM combined with the mentioned channel coding is called COFDM (Coded Orthogonal Frequency Division Multiplex). System using this form of signalling have of recent years been implemented for different types of broadcasting, i.e. one-way systems for digital broadcasting and for digital TV.

The Patent document EP 448 493 describes a system for transmission of TV digitally. The picture information is transmitted to a mobile user and is divided into two parts; one is used to recreate a normal TV-picture and the other together with the first one to create a larger picture. In the document EP 441 732 is described a receiver for digital radio signals. The receiver utilizes a window method to minimize the intersymbol interference arising at multipath propagation. In order to reduce the negative effects at the loss of the orthogonality of the carriers at the reception, the receiver will be equipped with a time window module which is used to extract usable samples from the received signal.

The American document US 5 228 025 describes a method to transmit digital data via radio, preferably to mobile receivers. The method transmits a synchronization sequence in the form of at least one frequency which varies in one for the receiver known way. At the receiver the synchronization sequence is utilized for tuning the local oscillator.

In the first prototype for transmission and reception of DAB (Digital Audio Broadcasting) two sync symbols are used. The first is called zero symbol and contains nothing but is used by the receiver on one hand for symbol synchronization, and on the other for estimation of interference in the channel. The second symbol consists of a so called chirp or sine sweep signal which is a sine shaped signal, the frequency of which changes linearly with time and which sweeeps over the whole channel width. This is used by the receiver on one hand for adjustment of the location of the time window, i.e. division of the received signal in segments which are each processed by means of FFT, and on the other for

estimation of the transmission function of the channel and estimation of deviations in the carrier frequency, if any. In the final DAB-specification the chirp symbol has been replaced by a so called TFPC-signal (Time Frequency Phase Control), also called CAZAC-symbol, which is used by the receiver both for timing, frequency adjustment and for estimation of the transmission function.

DESCRIPTION OF THE INVENTION/TECHNICAL PROBLEM

Transmission of information by means of OFDM-technology makes quite different demands upon accuracy than in conventional systems. The normal synchronization which takes place between transmitter and receiver in conventional broadcasting systems is at transmission of program information in digital form with COFDM not sufficient. There is, accordingly, a need for accurate estimation of frequency, time window, sampling clock and compensation of phase noise.

THE SOLUTION

The present invention relates to a method for correction of frequency, time window, sampling clock and time variable phase error at OFDM-reception. One from a transmitter transmitted signal is received by the OFDM-receiver. The signal, which is divided into consecutive frames, which each in its turn is divided into symbols, contains with certains intervals reference symbols with a predetermined content. Each frame is divided into a number of symbols which regarding time follow each other. Respective symbol is allotted a serial number, and the mentioned reference symbols are preferably

transmitted in pairs. The receiver analyzes the different reference symbols. The signals in the reference symbols consist of so called chirp signals, i.e. so called sine sweeep signals which are sine signals the frequency of which is linearly changed with the time and which sweeps over the whole channel width. One of the chirp signals goes from the highest frequency to the lowest in time, and the other chirp signal from the lowest frequency to the highest frequency. The relation between the contents of the reference symbols in pair regarding time and frequency is utilized for adjustment of the frequency of the receiver. Further, the impulse response is calculated from the signals of the received reference frames at which correction of time window and sampling clock can be performed. The main focus of the impulse response is determined, at which the real position of the time window can be determined. By means of the obtained result the position of the time window is adjusted in relation to wished position by the sampling clock being adjusted in relation to the difference between the mentioned main focus and wished position. Each symbol consists of a number of superimposed carriers with among themselves different frequencies. For each of the carriers further is arranged that its phase and amplitude, which can also be described by its real and imaginary part, is modulated by the data information which shall be transmitted. The mentioned real and imaginary parts are allotted a definite position in a matrix system. In the matrix system real and imaginary parts are allowed to take different positions which are accepted. The relation between the point which is indicated by received real and imaginary part and the ideal position in the matrix indicates an angle difference to the ideal position which is utilized for correction of the phase error at reception.

ADVANTAGES

The indicated method gives a possibility to make accurate adjustments of the receiver in a way which has not previously been possible and which gives increased robustness at OFDM-reception. The method further allows that the necessary adjustments in the receiver are possible to perform in a simple way. The method thus allows that the program transmission can be performed with the high precision which is expected in these connections.

DESCRIPTION OF FIGURES

Figure 1 shows schematically how the receiver at first locates the chirp signals by means of a set of binary correlators and after that precision adjusts time window, carrier frequency and phase according to the invention.

Figure 2 shows how the OFDM-signal is created by means of IFFT (Invers Fast Fourier Transform). Each entry on the IFFT corresponds to a carrier.

Figure 3 shows the matrix for estimation of phase error with points according to the 16QAM-system and illustrates the angle relation between the real position of the received vector and the ideal position.

DETAILED EMBODIMENT

A signal sequence is transmitted from a transmitter and received by a receiver. The signal sequence comprises a number of symbols which are arranged to a frame. At the

beginning of each frame one or more synchronization symbols are arranged. At least two of the mentioned synchronization frames contain so called chirp signals. A chirp signal is a sine signal the frequency of which is changed linearly with time. In order to detect the position of the chirp signal a set of correlators are used. The auto correlation for a chirp signal has a very acute maximum. In the receiver the symbol bit of the chirp signal is received and is compared with a stored signal. The signal is compared by being processed through a number of XNOR-gates. The number of equal bits, i.e. the hamming weight of the resulting vector is obtained as an output signal from the correlator. The synchronization signals which at that are obtained in 1 in Figure 1 are brought back to a frame structure generator, 2 in Figure 1, which controls division of the incoming signal in frames and symbols, and numbers the individual samples within each symbol. The frame structure generator in this way controls the division of the signal in appropriate time windows to the FFT (Fast Fourier Transform). The symbols coming out from the FFT are after that forwarded to among other things a signal processor, 3 in Figure 1, where correction values for carrier frequency and the frequency of the sampling clocks is calculated. The transmitted signal from the transmitter has been created by means of an IFFT (Inverse Fast Fourier Transform) according to Figure 2. For an up-chirp signal each of the carriers has been given an amplitude and phase according to he formula $e^{j\pi k^2}/N$, where k corresponds to the number of the carrier, and N the number of carriers. A down-chirp signal is created in a similar way but with negative phase; consequently the formula becomes $e^{-j\pi k^2}/N$. The received signal is made subject to a Fast Fourier Transform (FFT) in the receiver. The correction

calculations which are performed in unit 3 in Figure 1 implies that a multiplication by the for the carrier allotted inverse angle is performed by received up-chirp being multiplied by an ideal down-chirp, and that received down-chirp is multiplied with an ideal up-chirp. The in this way obtained signals, which we call de-rotated chirps, each constitutes an estimate of the transmission function of the channel. For an ideal channel these estimates become equal to 1 for all carriers. If a shift of the carrier frequency has occurred somewhere in the channel, the de-rotated chirps will have a remaining phase shift which is linearly depending on the serial number of the carrier. The changes get different symbols in the up- and the down-chirp. The phase positions of the de-rotated chirps are also influenced by frequency selective fading and by wrong setting of the time window, but this influence has the same symbol in both chirps. Therefore the carrier error can be extracted by subtraction of the de-rotated phase positions of one of the chirps from the other. Then the influence of the carrier error is doubled, whereas other influence is eliminated. The numerical value of the carrier error can in one in itself known way be estimated from the phase position´s linear depending on the carrier number. The obtained number is after that utilized in an in itself known way to correct the frequency.

The impulse response of the channel is obtained by an IFFT-transform on the de-rotated chirps. In order to reduce the influence of the noise on the main focus calculation the impulse response is multiplied with a weighting function before the position of the main focus is calculated. The difference between this position and a predetermined wished position constitutes a correction signal which after filtering controls the

clock-frequency of the A/D-converter, at which the correction value successively will be adjusted towards zero. Consequently the time window will land up in wished position.

The impulse response of the channel can be estimated both from received up-chirp and down-chirp. It is to advantage to use the sum of these two estimates at the main focus calculation because an error in carrier frequency will influence the position of the main focus with different symbols depending on whether it is calculated on an up-chirp or on a down-chirp. The main focus position of the sum of the two impulse responses will therefore be insensible to errors in carrier frequency because the error will neutralize itself.

The received carriers are arranged in a matrix system with respect to their imaginary respective real part. These points are in the complex number plan allotted an area within which they are allowed to exist. A point in the complex number plan which occur within the mentioned area is regarded to symbolize a certain transmitted data sequence. The relation of the point to the ideal position indicates an angle relation between the ideal position and the real position. The mentioned angle difference indicates the phase error in the reception. The average of the angle differences calculated from all the different carriers in the same symbol constitutes an estimate of the phase error. The in this way obtained phase error can after that be combined with previously obtained phase errors and be utilized for phase correction of all carriers in the symbol in question, and for estimation of the expected phase error at the reception of next symbol. It can also be used for estimation of small frequency deviations because these

give rise to phase errors with constant change from symbol to symbol.

The mentioned method for estimation of the phase error can be further developed in different ways. Two different improvements of the method have been identified. One or both improvements can be applied.

The first improvement is based on the fact that the amplitude of the received signal on one and the same occasion can be of different strength for different carriers, frequencies. This is due to interference from reflections of the signal, so called multipath propagation, or interference from other transmitters which transmits the same signal in a so called single frequency network. The carriers which are subject to destructive interference are weakened and get a worse signal/noise-relation than the other. The frequency depending transmission function for the channel can be calculated in the receiver by analysis of the received chirps. At calculation of the average of the angle differences the values from the different carriers can be weighted with the calculated transmission function at which angle differences from carriers with high attenuation in the channel is given a lower weight than those with low attentuation. The strong noise from the attenuated carriers can by that be made to have a minimal influence on the estimation of the phase error.

The second improvement is based on the fact that one and the same noise effect in the received signal gives different uncertainty in the estimation of the phase error for signals far from or close to the origin of coordinates. In order to bridge this state of things the mentioned angle relations are weighed in relation to the distance to the origin of coordinates.

The invention is not restricred to the above as example shown embodiment but may be subject to modifications within the frame for the following patent claims and idea of invention.

PATENT CLAIMS

1. Method at OFDM-demodulation for correction of carrier frequency, phase error, time window and frequency of sampling clock, at which one at the OFDM-receiver received signal is divided into symbols and at defined intervals is allotted symbols and on defined intervals are allotted reference symbols with a predetermined content, and the signal comprises a number of carriers where each carrier is allotted a serial number and the reference symbols can be transmitted in pairs, c h a r a c t e r i z e d in that the received reference symbols are analysed in the receiver, that the contents of the received reference symbols with respect to time and frequency indicate how the carrier frequency in the receiver shall be adjusted, that the impulse response of the channel is calculated from the signals of the reference symbols at which correction of the time window and the frequency of the sampling clock is performed, that the position of the complex vectors of the received demodulated carriers is compared with an ideal position at which deviation from the mentioned ideal position is utilized for correction of the phase error at the reception.

2. Method according to patent claim 1, c h a r a c t e r i z e d in that the position of the complex vectors of the received demodulated carriers are arranged in a matrix system with respect to their imaginary respective real part, that each vector is allotted an area within which it is indicated to exist, and that a vector occurring within mentioned area is at a certain angle distance from the ideal position, and that the mentioned angle distance is utilized for calculation of the phase error.

3. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the amplitude of the received signal is different in strength for different carriers depending on whether the receiver receives more signals, that the phase error estimation for respective carrier is weighted depending on the amplitude of the transmitting function at current frequency, at which a signal with higher amplitude is given a higher weighting than a signal with lower amplitude.

4. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the vectors depending on their amplitude, i.e. their distances from the origin of coordinates, are given different weights, which weights compensate for the amplitude depending influence of the noise on the angle error, at which the angle distance farthest away from the origin of coordinates is allotted a higher weighting than those which are close to the origin of coordinates, and that a correction of the phase error is performed corresponding to the weighted angle error.

5. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the latest obtained phase error is compared with previously obtained phase error and that the expected phase error at reception of next sequence is calculated.

6. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the position of the main focus of the impulse response of the channel is determined, which position indicates the real position of the time window, and that the position of the time window is adjusted in relation to the difference between real position and wanted position by

the frequency of the sampling clock being adjusted in relation to the mentioned difference.

7. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the reference symbols are related to the frequency of respective carrier.

8. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the contents of the reference symbols consist of chirp signals.

9. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the reference symbols are transmitted in pairs at which the reference symbols in pairs are allotted one a up-chirp and the other a down-chirp.

10. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the up-chirps is defined by $e^{j\pi k^2/N}$ and in the down-chirps by $e^{-j\pi k^2/N}$, where N represents the number of carriers, k the serial number of respective carrier, and $j^2 = -1$.

AMENDED CLAIMS

[received by the International Bureau on 19 April 1996 (19.04.96); original claims 1-10 replaced by amended claims 1-7 (2 pages)]

1. Method at OFDM-demodulation for correcting of carrier frequency, phase error, time window and frequency of sampling clock, at which one at the OFDM-receiver received signal is divided into symbols and at defined intervals is allotted symbols and on defined intervals are allotted reference symbols with a predetermined content, and the signal comprised a number of carriers where each carrier is allotted a serial number and the reference symbols can be transmitted in pairs, the received reference symbols are analysed in the receiver, and the contents of the received reference symbols with respect to time and frequency indicate how the carrier frequency in the receiver shall be adjusted, the impulse response of the channel is calculated from the signals of the reference symbols at which correction of the time window and the frequency of the sampling clock is performed, the position of the complex vectors of the received demodulated carriers is compared with an ideal position at which deviation from the mentioned ideal position is utilized for correction of the phase error at the reception, c h a r a c t e r i z e d in that amplitude and phase of the carriers in the reference symbols are related to the frequency of respective carrier.

2. Method according to patent claim 1, c h a r a c t e r i z e d in that the position of the complex vectors of the received demodulated carriers are arranged in a matrix system with respect to their imaginary respective real part, that each vector is allotted an area within which it is indicated to exist, and that a vector occurring within mentioned area is at a certain angle distance from the ideal position, and that the mentioned angle distance is utilized for calculation of the phase error.

3. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the amplitude of the received signal is different in strength for different carriers depending on whether the receiver

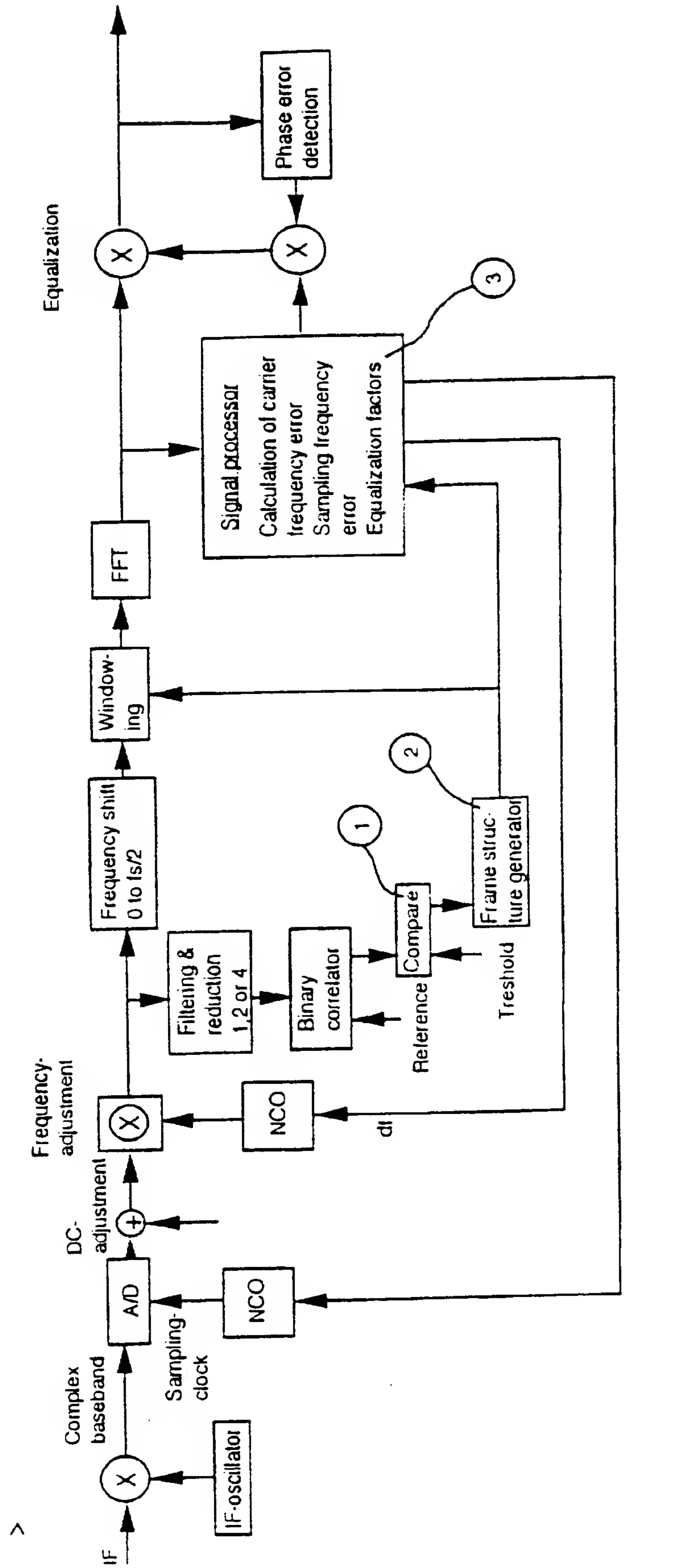
receives more signals, that the phase error estimation for respective carrier is weighted depending on the amplitude of the transmitting function at current frequency, at which a signal with higher amplitude is given a higher weighting than a signal with lower amplitude.

4. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the vectors depending on their amplitude, i.e. their distances from the origin of coordinates, are given different weights, which weights compensate for the amplitude depending influence of the noise on the angle error, at which the angle distance farthest away from the origin of coordinates is allotted a higher weighting than those which are close to the origin of coordinates, and that a correction of the phase error is performed corresponding to the weithted angle error.

5. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the latest obtained phase error is compared with previously obtained phase error and that the expected phase error at reception of next sequence is calculated.

6. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the position of the main focus of the impulse response of the channel is determined, which position indicates the real position of the time window, and that the position of the time window is adjusted in relation to the difference between real position and wanted position by the frequency of the sampling clock being adjusted in relation to the mentioned difference.

7. Method according to any of the previous patent claims, c h a r a c t e r i z e d in that the contents of the reference symbols consist of chirp signals.


IF
IF-oscillator
Complex baseband
Sampling-clock
A/D
NCO
DC-adjustment
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NCO
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Compare
Treshold
1
Frame struc-ture generator
2
Frequency shift 0 to fs/2
Window-ing
FFT
Signal processor
Calculation of carrier frequency error
Sampling frequency error
Equalization factors
3
Equalization
Phase error detection

Figure 1

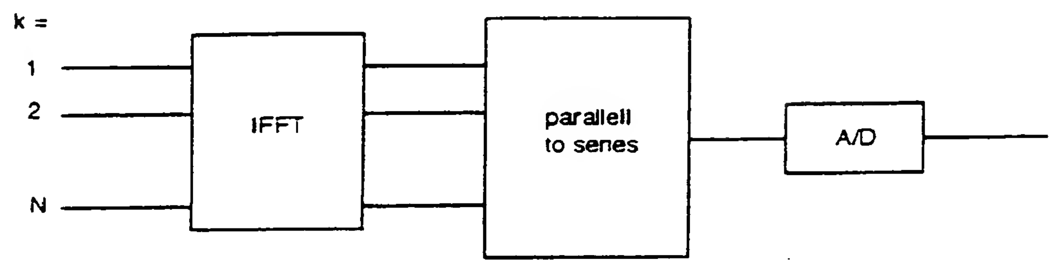

Figure 2

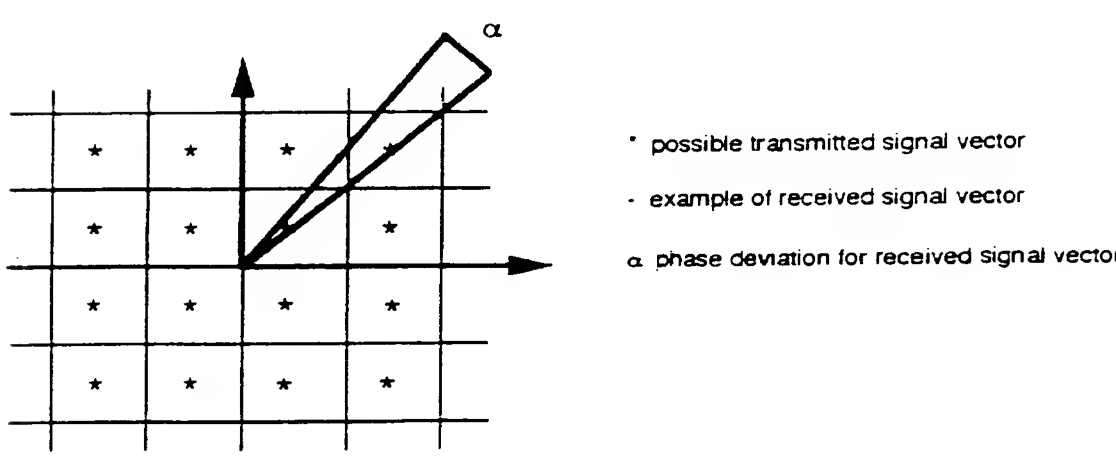

Figure 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 95/01413

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 5/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0529421 A2 (DAIMLER-BENZ AKTIENGESELLSCHAFT), 3 March 1993 (03.03.93), page 3, line 15 - line 41; page 6, line 1 - line 8; page 8, line 6 - line 21, abstract	1,8
Y		2,3,5
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Y	US 5345440 A (J. GLEDHILL ET AL), 6 Sept 1994 (06.09.94), column 8, line 1 - column 9, line 55, figure 5	2
	--	
Y	EP 0618697 A2 (GRUNDIG E.M.V.), 5 October 1994 (05.10.94), page 5, column 52 - column 58	3,5
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
19 March 1996	21 -03- 1996
Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Göran Magnusson Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

05/02/96

International application No.
PCT/SE 95/01413

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		WO-A- 9212792	06/08/92
EP-A2- 0618697	05/10/94	NONE	

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04B 1/707

A1

(11) International Publication Number: WO 96/24988

(43) International Publication Date: 15 August 1996 (15.08.96)

(21) International Application Number: PCT/FI96/00076

(22) International Filing Date: 9 February 1996 (09.02.96)

(30) Priority Data:
950600 10 February 1995 (10.02.95) FI

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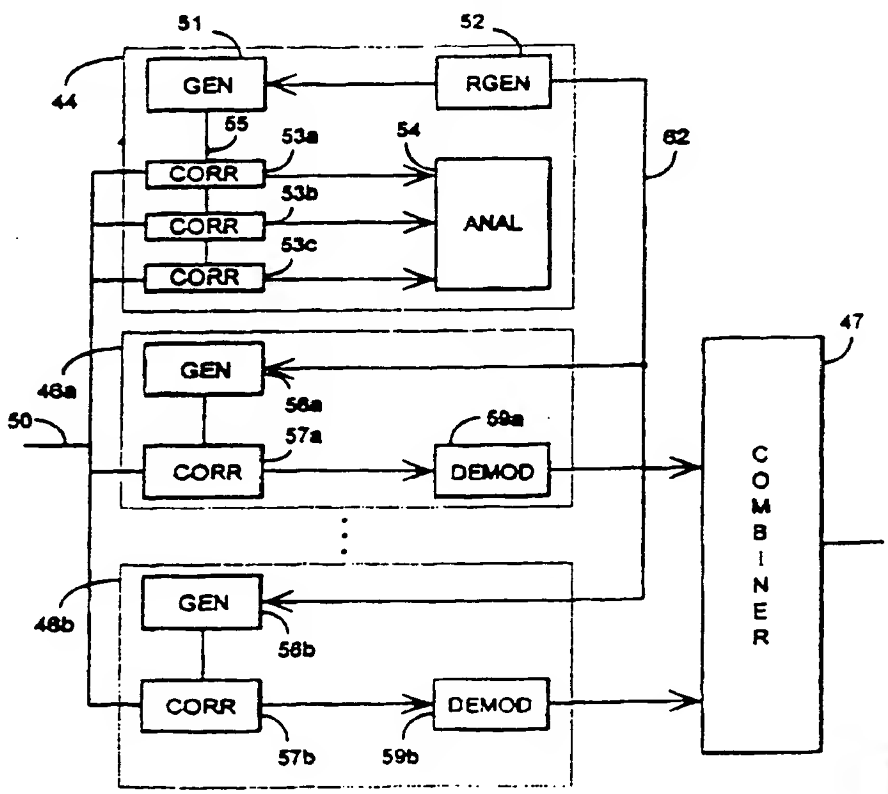
(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AZ, BY, KG, KZ, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: RECEIVER AND METHOD FOR GENERATING SPREADING CODES IN A RECEIVER

(57) Abstract

The invention relates to a method for generating spreading codes in a receiver, and a receiver for use in a system wherein a signal to be transmitted is multiplied with a code sequence characteristic of each connection, the receiver comprising means (44) for estimating a channel, and one or several demodulator means (46a, 46b), and means (47) for combining signals obtained from the demodulator means (46a, 46b). In order to enable the use of long codes and to facilitate the internal synchronization of the receiver, the receiver according to the invention comprises a number of means (51, 52, 56a, 56b) for generating a code sequence, the first means (51, 56a, 56b) producing a code sequence at a variable phase, and the second means (52) producing a code sequence the phase of which acts as a reference to the first means (51, 56a, 56b).



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Receiver, and method for generating spreading codes in a receiver

The invention relates to a receiver for use in a system wherein a signal to be transmitted is multiplied with a code sequence characteristic of each connection, the receiver comprising means for estimating a channel, and one or more demodulator means, and means for combining signals received from the demodulator means.

The invention further relates to a method for generating spreading codes in a receiver, in which method a signal to be transmitted is multiplied with a code sequence characteristic of each connection, and in which receiver signal components transmitted with the desired code are sought from the received transmission, and the phases of the components are measured by correlating the received transmission with the code sequence generated in the receiver.

The receiver and the method according to the invention can be applied especially in a cellular system utilizing code division multiple access.

CDMA (Code Division Multiple Access) is a multiple access method, which is based on the spread spectrum technique and which has been applied recently in cellular radio systems, in addition to the prior FDMA and TDMA methods. CDMA has several advantages over the prior methods, for example spectral efficiency and the simplicity of frequency planning.

In the CDMA method, the narrow-band data signal of the user is multiplied to a relatively wide band by a spreading code having a considerably broader band than the data signal. In known test systems, bandwidths such as 1.25 MHz, 2.5 MHz and 25 MHz have been used. In connection with multiplying, the data signal spreads to

the entire band to be used. All users transmit by using the same frequency band simultaneously. A separate spreading code is used over each connection between a base station and a mobile station, and the signals of the users can be distinguished from one another in the receivers on the basis of the spreading code of each user.

A CDMA receiver comprises means, which can be implemented for example with correlators or matched filters, for synchronization with a desired signal, which is recognized on the basis of the spreading code. In the receiver, the data signal is restored to the original band by multiplying it again by the same spreading code as during the transmitting stage. Signals multiplied by some other spreading code do not correlate in an ideal case and are not restored to the narrow band. They appear thus as noise with respect to the desired signal. The spreading codes of the system are preferably selected in such a way that they are mutually orthogonal, i.e. they do not correlate with each other.

In a typical mobile phone environment, the signals between a base station and a mobile station propagate along several paths between the transmitter and the receiver. This multipath propagation is mainly due to the reflections of the signal from the surrounding surfaces. Signals which have propagated along different paths arrive at the receiver at different times due to their different transmission delays. CDMA differs from the conventional FDMA and TDMA in that the multipath propagation can be exploited in the reception of a signal. One way of realizing a CDMA receiver is to use for example a so-called rake receiver, which consists of one or more rake branches. Each branch is an independent receiver unit, the function of which is to compose and demodulate one

received signal component. Each rake branch can be caused to synchronize with a signal component which has propagated along an individual path, and in a conventional CDMA receiver the signals of the receiver branches are combined advantageously, for example coherently, whereupon a signal of good quality is obtained. The signal components received by the receiver branches may be transmitted from one base station, or in the case of macrodiversity, from several base stations. The realization of a rake branch is described in greater detail in G. Cooper, C. McGillem: *Modern Communications And Spread Spectrum* (McGraw-Hill, New York, 1986, Chapter 12).

In mobile network applications, the use of long spreading codes provides several advantages. The sufficient length of the spreading code enables almost an unlimited number of different code sequences (by means of which the signals of different users are distinguished from one another), the easy application of cryptographic algorithms, and the use of the same long code at different phases in synchronous networks. In connection with using long codes, the magnitude of the delay spread is unlimited.

The use of long codes has been difficult so far, however, since there are a number of problems related to their use. The code search periods may become long whereupon the synchronization is slow. When long codes are used, the network should typically be synchronous. The receiver must also detect the signal from a partial correlation result, which does not produce an ideal result. In a rake receiver, there may occur problems in code search, measurement of impulse response, the activation of rake branches to receive different signal components, code tracking and synchronization of transmitter and receiver directions.

An example of a system utilizing long codes and having the aforementioned problems is the IS-95 standard suggestion, which is incorporated herein by reference.

The purpose of the present invention is to realize the use of long codes especially in a rake receiver in such a way that the generation of codes and the timing between different receiver blocks can be controlled.

This is achieved with the receiver of the type described in the preamble, characterized in that the receiver comprises a number of means for generating a code sequence, the first means producing a code sequence at a variable phase, and the second means, of which there is at least one, produce a code sequence the phase of which acts as a reference to the first means.

The method according to the invention is characterized in that at least two code generators are utilized in the search of the different signal components of the transmission multiplied with the desired code and in the measurement of the phases of the components, so that the first code generator produces a variable-phase code sequence, and the second code generator produces a code sequence the phase of which is attached to a detected signal component.

The receiver according to the invention knows at all times the common timing, i.e. the phase of the reference code generator, regardless of the reception situation, i.e. whether the receiver is in the process of searching, measuring the impulse response or demodulating. The changes in the code phase of the variable-phase code generator do not have to be recorded. The code tracking may change the phase of the generator in such a way that the signal level is maximized without a need to inform the other parts of the receiver of the changes.

In the receiver according to the invention, it is sufficient in the activation of the rake branches that the demodulation branch is informed of the phase difference of the desired component with respect to the reference phase. The amount of the information to be transmitted is thus a few bits. For example in the IS-95 standard, the rake branch should be informed of the state of the entire generator, i.e. the contents of the shift register, which means a 42-bit message or a suitable bus for transmitting information.

In the following, the invention will be described in greater detail with reference to the examples according to the accompanying drawings, in which

Figure 1 illustrates a part of a cellular system wherein the method according to the invention can be applied,

Figure 2 illustrates in greater detail a connection between a base station and a subscriber terminal,

Figure 3 shows an example of an impulse response typical of a radio connection,

Figure 4 is a block diagram illustrating an example of a receiver according to the invention,

Figure 5 is a block diagram illustrating in greater detail an example of a receiver according to a preferred embodiment of the invention,

Figure 6 is a block diagram illustrating in greater detail another example of a receiver according to the invention,

Figure 7 illustrates a possible way of generating spreading codes,

Figure 8 shows the distribution of a code sequence to different correlators, and

Figure 9 is a timing diagram illustrating measurement of an impulse response.

Figure 1 illustrates a part of a cellular system wherein the method according to the invention can be applied. The system comprises a base station 10 which has a bidirectional connection 11 to 13 with subscriber terminals 14 to 16. Each connection typically uses its own spreading code with which the information to be transmitted is multiplied and thus spread to a broad frequency band. On the basis of the spreading code, the receivers can distinguish the desired signal from the other signals transmitted on the same frequency band. The method according to the invention can be applied and the receiver arrangement according to the invention can be utilized both in a terminal equipment and at a base station.

Figure 2 illustrates in greater detail the connection between a terminal equipment and a base station in the transmission direction from the terminal equipment 14 to the base station 10. As described above, in a typical cellular environment the signals between a terminal equipment and a base station propagate along several different paths between the transmitter and the receiver. This multipath propagation is thus mainly due to the reflections of the signal from the surrounding surfaces. The figure shows the propagation of the signal from the terminal equipment 14 along three different paths 20a to 20c to the base station receiver. Since these signals, which hereafter will be called signal components, have propagated along paths of different lengths between the transmitter and the receiver, they arrive at the receiver at slightly different times and with different phases. This is illustrated in Figure 3 which shows the impulse response of the radio channel by way of example. The aforementioned three signal

components are visible in the impulse response as peaks 30 to 32 that are not simultaneous. The function of the CDMA receiver is to measure the impulse response, i.e. to find the different signal components of the transmitted signal within a certain delay window, to synchronize itself, to demodulate the desired signal components and to combine the demodulated signals advantageously.

Figure 4 is a block diagram generally illustrating an example of a receiver according to the invention. The receiver according to the invention comprises an antenna 40 receiving signals that are supplied to radio-frequency parts 41, wherein a signal is converted to an intermediate frequency. From the radio-frequency parts 41 the signal is further supplied to converter means 42 wherein the received analog signal is converted into digital form. The described radio-frequency parts 41 and the converter means 42 can be implemented with known manners. The receiver further comprises a rake receiver block 43 wherein the received signal is demodulated, and means 45 for decoding the signal.

The rake receiver block 43 comprises channel-estimation means 44, a number of demodulator branches, or rake branches, 46a to 46c, and means 47 for advantageously combining the demodulated signals. The function of the channel-estimation means 44 is to perform on the received signal the search for the signals transmitted with the desired spreading code, the initial synchronization thereof, and the measurement of the channel impulse response, i.e. the search for and measurement of the different signal components of the signal multiplied with the desired spreading code within a certain delay window. On the basis of the measurements performed by the channel-estimation block 44, the rake

branches 46a to 46c are activated to receive each their own signal component. The strongest signal components are typically selected for the demodulation. When the receiver is a subscriber terminal receiver, the channel-estimation means 44 are also intended to search for the signals of the neighbouring channels.

The number of the rake branches 46a to 46c in the receiver depends on the application wherein the receiver is used. In a cellular network, the criterion is the number of the multipath-propagated signal components to be distinguished from the radio channel. Each rake branch can be activated to receive one signal component. The spectrum of the wide-band signal component received in the rake branch is composed by correlating the signal component with a reference signal which is at a corresponding phase as the delay of the input signal and which may be a signal produced by a binary code generator. Data concerning the delay of the received signal component, which is required for the synchronization of the rake branch with the signal, is thus obtained from the channel-estimation means 44.

The composed signal is demodulated in the rake branch either coherently, incoherently or differentially coherently, according to the modulation of the received signal. If coherent demodulation is used, the phase of the signal must be known. A data-unmodulated pilot signal is typically used for the estimation of this phase, as it is known to a person skilled in the art. The code phase of the signal received in the rake branch is monitored with a code-tracking loop which may utilize either a data signal or a pilot signal. The signal components that are received and demodulated in the different rake branches are advantageously combined in the means 47. For the combining, the components can be weighted in a desired manner in the rake branches.

Optimal diversity combination is thus performed on the signal components in the means 47. The combination of the signal components may be either coherent or incoherent, depending on the application. The means 47 further comprise a decision logic, which makes either a hard or a soft decision from the information symbols of the combined signal. The detected symbols are further supplied to a channel decoder 45. The combining means 47 can be realized in known manners in the receiver according to the invention. It is evident for a person skilled in the art that the receiver naturally comprises also components other than the ones described above, for example filters and speech coders depending on the type of the receiver, but for the sake of simplicity they have been left out as components not essential to the invention.

In the following, the block diagram of Figure 5 is used to describe in greater detail a part of a receiver implementing a preferred embodiment of the invention, and the function of the receiver. The receiver thus comprises a channel-estimation block 44 the function of which is to locate and measure signal components multiplied with a desired spreading code. The receiver according to the invention comprises in the channel-estimation block 44 at least two code generators 51, 52 the output of which provides the desired spreading code having the desired phase. In the beginning when the receiver is not yet active, the code generators 51, 52 are initialized to the same phase. A typical code generator produces an M sequence, and in such a case the desired generator polynome and the initial state of the coder are initialized in the generator. A possible implementation of the generator is described further on. The coder may be started for example by means of an external starting signal.

Code search

The code generator 51 produces a code sequence that is at the original phase and that is supplied to a number of correlators 53a to 53c wherein the received signal is correlated. Figure 8 shows in greater detail the distribution of the code sequence from the code generator 51 to the different correlators 53a to 53c. The code sequence is supplied to the different correlators preferably via delay units 80a, 80b, whereupon each correlator 53a to 53c calculates the correlation with a sequence that is at a slightly different phase with the input signal 50 and the code sequence. This provides parallel calculation for successive samples. The number of the correlators 53a to 53c in the channel estimator may vary depending on the application. The correlation results of the correlators are supplied to a measurement-analysing block 54 wherein the obtained result is compared with a given threshold value, which reveals whether the received signal level is sufficiently high. If no signal has been detected, the code phase of the code generator 51 is shifted to the next code phase according to the desired measurement resolution. New measurements are performed with the new code phase in the correlators 53a to 53c, and the results are analyzed in the block 54. The operation continues until a sufficiently strong signal can be detected.

When a sufficiently strong signal level is detected, the phase of the code generator 51 is not altered, but the correlation result is calculated several times with the same code phase, and the average signal level is calculated with the aforementioned code phase. If the obtained averaged measurement result still shows that a sufficiently strong signal component is received with this code phase, the code phase is

accepted as the correct one for the signal that is searched for. Otherwise the search is continued by changing further the phase of the code generator 51 according to the desired measurement resolution. The code phases are systematically checked with this method until the desired signal is found.

When the signal components and the corresponding code phase of the desired signal have been found in the above-described manner, the code timing of the rake receiver can be initialized on the basis of the received signal in such a way that the code phase with which the signal was found is set as the reference phase. This is done by initializing the phase of the reference code generator 52 to the same phase as the phase of the generator 51 which is thus the same code phase with which the signal was found. The phase of the reference code generator 52 is kept constant, i.e. it acts as a reference for the other code generators of the receiver. Its phase is not changed during the code search as in the case of the first code generator 51. The phase of the reference code generator 52 is only altered if the total timing of the receiver changes.

In the receiver according to a preferred embodiment of the invention illustrated in Figure 5, each rake branch 46a, 46b comprises two code generators 56a, 58a, and 56b, 58b, respectively, the output of which provides the desired spreading code at the desired phase. As in the channel-estimation block 44, in each rake branch one code generator 58a, 58b is reserved as a reference generator. When the code search produces a signal, the corresponding code phase is initialized not only in the reference code generator 52 of the channel-estimation block, but also in each reference code generator 58a, 58b of the rake branch by means of a bus

60. All the reference code generators 52, 58a, 58b of the receiver are thus always at the same phase.

Figure 6 illustrates a second embodiment of the invention wherein the receiver comprises one reference code generator 52 that is common to the channel-estimation block 44 and the rake branches 46a to 46b. This requires less components than the arrangement of Figure 5, but the amount of the information to be transmitted between different parts of the receiver is greater.

If M sequences are used as the spreading codes, which is typical, the sequences are generated by means of shift registers, and the code phase is then initialized by setting the state of the coder, i.e. the contents of the shift register, to the desired one. In this case, the contents of the shift registers of the code generator 51 are copied to the shift registers of the reference code generator. This can be realized for example by means of a parallel output and a load pulse. Another method is to keep a record, during the search, of the number of code phases stepped in the generator 51 and to shift the phase of the reference generator 52 by the same number of steps for example by adding the clock frequency or by increasing or changing the clock frequency or by increasing or decreasing clock pulses.

Impulse response measurement

When the signal multiplied with the desired spreading code has been found with the above-described method, the function of the channel-estimation block 44 is to measure the impulse response in order to find the desired number of different signal components with which the rake branches 46a to 46c of the receiver could be synchronized. The operation of the channel-estimation block is in principle similar to the code search. The phase of the code generator is changed and a measurement

is performed for finding a transmission. However, since at least one code phase with which a signal is transmitted is known, the desired signal is now assumed to exist at certain code phases, whereupon the code phases have to be checked only within a delay window of a certain size. The size of the delay window, i.e. the greatest mutual delay difference between the different signal components of the same transmitted signal, depends on the propagation conditions of the radio signals, and in the cellular environment a suitable value can be selected as the delay window from the different propagation environments. All the significant multipath-propagated components of the signal, which can be utilized by the demodulator branches of the rake receiver, are assumed to fit inside this delay window. In the example of Figure 3, the delay window should contain three signal components 30 to 32, and a suitable window size would be the time window between the times 33 and 34 on the horizontal axis.

During the measurement of the impulse response, the phase of the reference generator 52 is not changed. The phase of the first code generator 51 is stepped over the delay window with the desired measurement resolution, which may differ from the resolution used in the code search. The analysing block 54 collects the correlation results in an amount corresponding to the delay window. The analysing block may also control the recharging of the code generator 51, i.e. it may shift the code phase of the generator 51 back to the beginning of the delay window. The measurement results obtained from each round of measurements are averaged to a final impulse response.

The timing diagram of Figure 9 illustrates the search for the impulse response. The code sequence is denoted by a line 90 and the correlators are stepped

according to the given measurement resolution 91 to 94, whereupon the measurement results provide in the example of the figure partial correlations 95 to 98 by means of which the different delay components can be detected. When the desired measurement window has been examined once for example after the measurement 94, the system goes back to the beginning of the delay window to measure from the area 91 for the purpose of averaging.

If the total timing of the received signal changes, which may result for example from a change in the distance between the terminal equipment and the base station, the place of the delay window is altered by stepping the code phase of the reference code generator 52 either backward or forward to correspond to the new timing. Margins comprising no received signal should be left before and after the delay window to be measured for a change in the timing. This ensures that changes forward and backward in the timing of the received signal are detected. In the example of Figure 3, margins 35, 36 have been left in the beginning and end of the delay window.

The changes in the timing may be monitored in the receiver by calculating the total energy of the signal over a certain delay spread, which is smaller than the measurement window. The energy of the signal can be calculated in a delay window situated in several different places within the measurement window. The measurement window determined by the reference code generator 52 should be preferably positioned in such a way that the entire delay spread of the signal is centred in the middle of the measurement window.

Activating the rake branches

The measurement result of the impulse response is compared with a given threshold level, and signal components exceeding this level can be utilized in the

receiver. The desired signal components can be received each with its own rake branch, demodulated, and combined advantageously. The activation of demodulation occurs by informing an available rake branch of the code generator phase corresponding to the signal component.

In the receiver arrangement of Figure 5, the rake branch is informed of the desired code phase as a relative difference to the phase of the reference code generator. The reference code generators 52, 58a, 58b of both the channel-estimation block 44 and all the rake branches 46a, 46b are at the same phase in the arrangement according to the invention. Data concerning the relative difference can be transmitted from the channel-estimation block to the rake branches by means of a few bits, i.e. the data does not require a long transmission time but it can be forwarded quickly, and no fast bus interface is required for the transmission, but a slower connection 61 is sufficient. In the rake branch, the code generator 57a, 57b is first set to the same phase as the reference code generator, and a number of steps, determined by the relative difference, are taken until the correct phase is obtained and the detection and monitoring of the desired signal component can be started. The reference phase is thus needed in the rake branches only in activation situations.

In the arrangement of Figure 6 wherein the reference code generator 52 is shared, the allocation of the rake branches occurs correspondingly in such a way that the phase of the reference code generator is loaded into the code generator, and the phase is deflected with a number of steps determined by the relative difference. As distinguished from the above, the reference code generator 52 and the code generators should be connected with a fast bus 62 over which the data concerning the generator state is transmitted. The

data concerning the relative difference can be transmitted over a slower line 61, as above.

The structure of the code generator is not significant in the receiver according to the invention, but the invention is applicable with code generators of all types. An example of a possible way of implementing a code generator is the aforementioned shift register structure with which M sequences that are generally used as spreading codes can be generated. Figure 7 is a block diagram illustrating a possible way of implementing a code generator by means of a shift register. The shift register comprises m stages 70 to 73 which are connected in series, and in which a modulo-2 adder 74a, 74b is coupled to the outputs of some stages via weighting coefficients 78a, 78b, the output of the adders being fed back to an input 75. All the stages 70 to 73 are timed simultaneously by means of a common clock signal 76. Whenever a clock pulse arrives, a new binary number arrives at the output 77.

If a specific phase of a specific code is to be set in the generator of the type described above, the desired values must be copied to the stages 70 to 73. The generators can be initialized either by means of software as the reading and writing operations of the processor 54, or by means of fixed connections.

Even though the invention is described above with reference to the examples according to the accompanying drawings, it is clear that the invention is not restricted thereto, but it can be modified in many ways within the scope of the inventive idea disclosed in the appended claims.

Claims

1. A receiver for use in a system wherein a signal to be transmitted is multiplied with a code sequence characteristic of each connection, the receiver comprising means (44) for estimating a channel, and one or more demodulator means (46a - 46c), and means (47) for combining signals received from the demodulator means (46a - 46c), c h a r a c t e r i z e d in that the receiver comprises a number of means (51, 52, 56a, 56b) for generating a code sequence, the first means (51, 56a, 56b) producing a code sequence at a variable phase, and the second means (52), of which there is at least one, produce a code sequence the phase of which acts as a reference to the first means (51, 56a, 56b).

2. A receiver according to claim 1, c h a r a c t e r i z e d in that the phase of the code sequence generated by the second means (52) is the same as the phase of a code sequence contained in a received signal component.

3. A receiver according to claim 1, c h a r a c t e r i z e d in that the means (44) for estimating a channel comprise means (53a - 53c) for correlating a received signal with a code sequence which is generated in the first means (51) for generating a code sequence, and means (54) which measure the magnitude of the correlation performed in the correlation means, and means (54) which control the phase of the code sequence of said first generation means (51).

4. A receiver according to claim 1, c h a r a c t e r i z e d in that the means (44) for estimating a channel and a group of demodulator means (46a, 46b) each comprise one first means (51, 56a, 56b)

generating a variable-phase code sequence and one second means (52, 58a, 58b) generating a code sequence acting as a reference.

5. A receiver according to claim 1, characterized in that the means (44) for estimating a channel and the group of demodulator means (46a, 46b) each comprise one first means (51, 56a, 56b) generating a variable-phase code sequence, and that the receiver comprises one second means (52) generating a code sequence acting as a reference.

6. A receiver according to claim 3, characterized in that the means (44) for estimating a channel comprise means (54) for informing the first generator means (56a, 56b) situated in the demodulator means (46a, 46b) of the desired code phase as relative deviation from the code phase of the other generation means (52, 58a, 58b).

7. A method for generating spreading codes in a receiver, in which method a signal to be transmitted is multiplied with a code sequence characteristic of each connection, and in which receiver signal components transmitted with the desired code are sought from the received transmission, and the phases of the components are measured by correlating the received transmission with the code sequence generated in the receiver, characterized in that at least two code generators are utilized in the search of the different signal components of the transmission multiplied with the desired code and in the measurement of the phases of the components, so that the first code generator (51) produces a variable-phase code sequence, and the second code generator (52) produces a code sequence the phase of which is attached to a detected signal component.

8. A method according to claim 7, characterized in that the phases of the

detected signal components are multiplied to the different demodulation blocks (46a - 46c) of the receiver as relative deviation of the phase of each component from the phase of the code sequence used as a reference.

9. A method according to claim 7 or 8, characterized in that when the first signal component is searched for in the beginning of the connection, the phase of the first code generator (51) is stepped with the desired resolution, and the correlation between the received transmission and the sequence generated by the first generator is calculated at each step until the calculated correlation exceeds a given threshold value, and that the code phase of the first generator at which the correlation was exceeded is copied to the second generator.

10. A method according to claim 9, characterized in that the second code generator (58a, 58b) of each demodulation block (46a, 46b) is initialized to the same phase as the second code generator (52) of the search block.

11. A method according to claim 9, characterized in that when the phases of the different components of the signal multiplied with the desired code sequence are measured from the received transmission, the first code generator (51) is stepped with the desired resolution around the phase of the second code generator (52) in a time window of desired size.

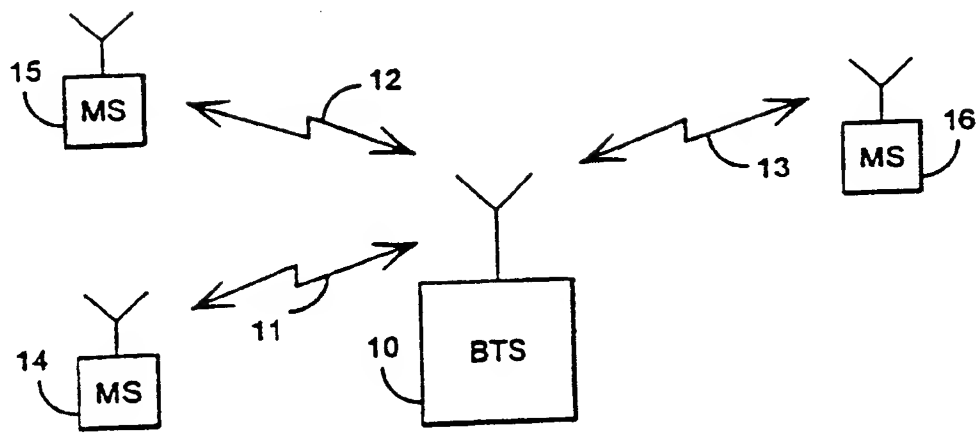


Fig. 1

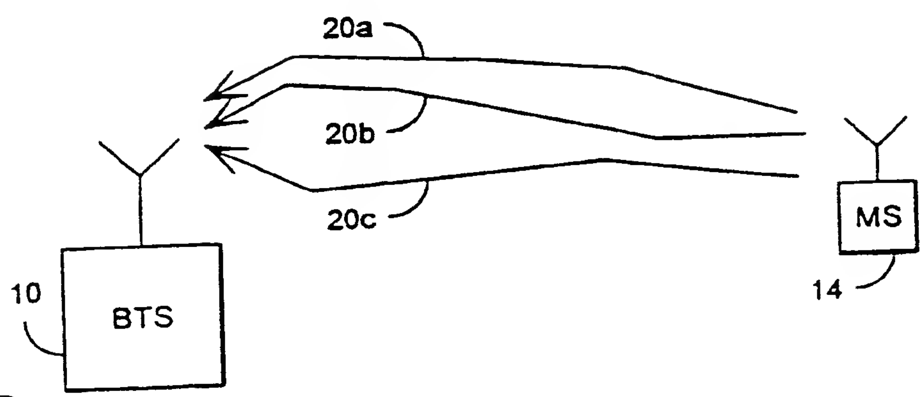


Fig. 2

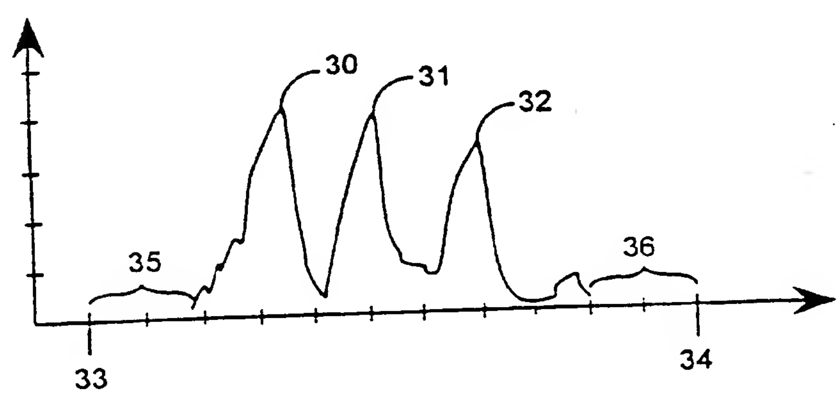
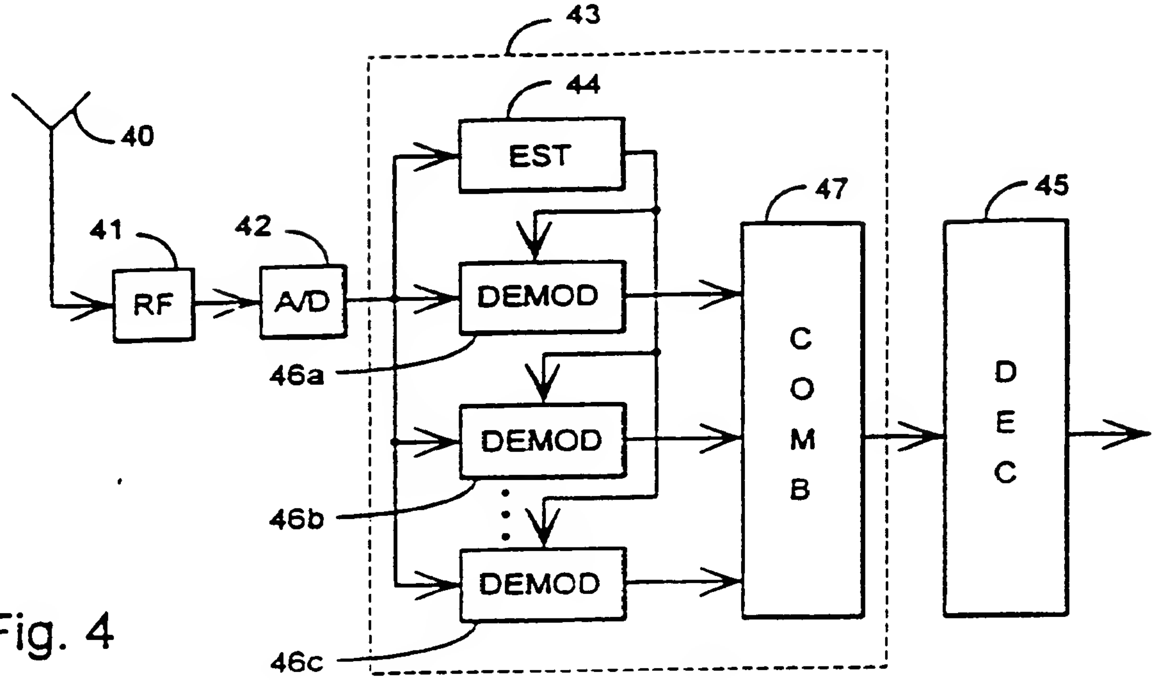


Fig. 3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C
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46b
DEMOD
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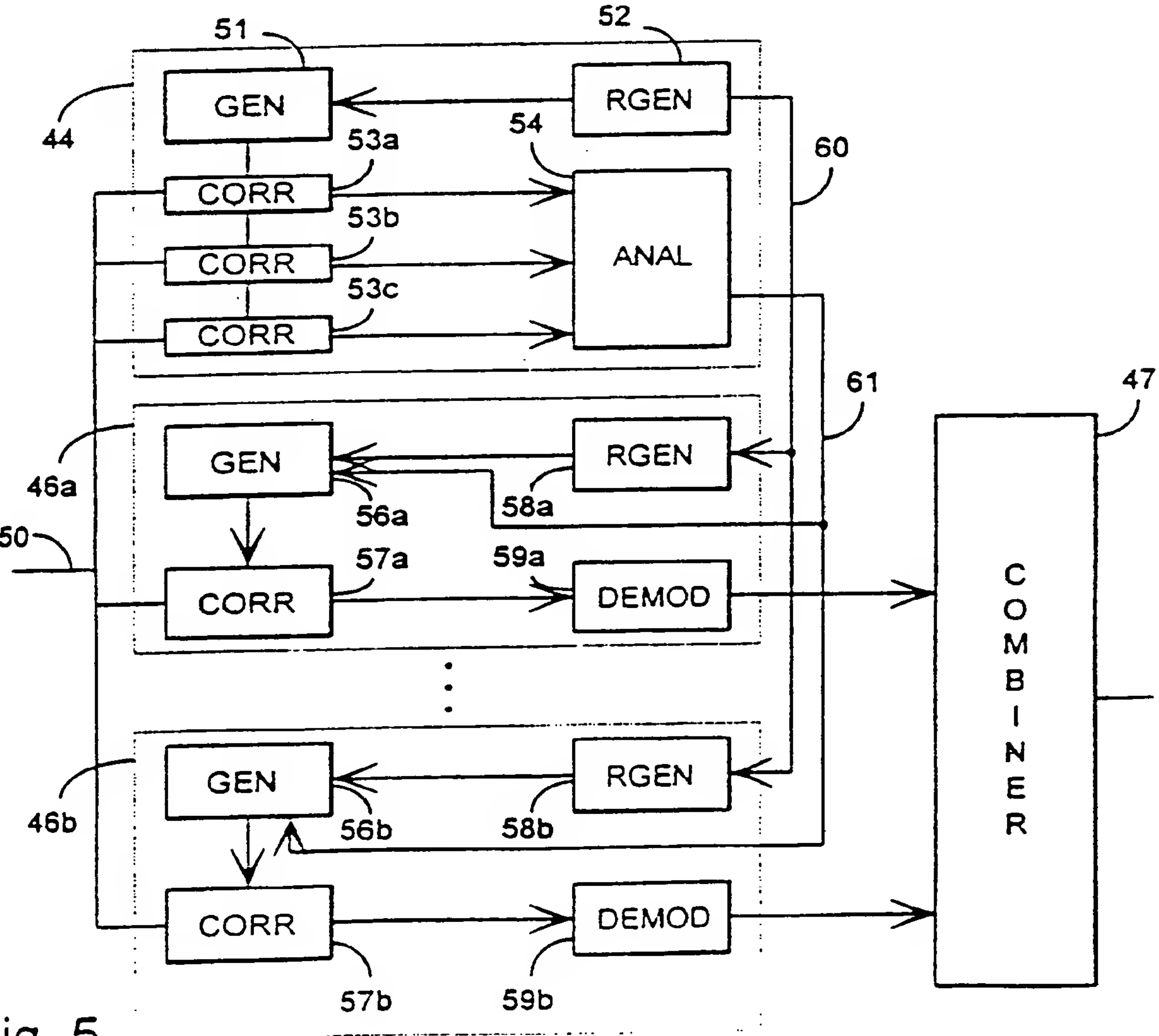
Fig. 4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56a
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50
57a
59a
CORR
DEMOD
C
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56b
58b
CORR
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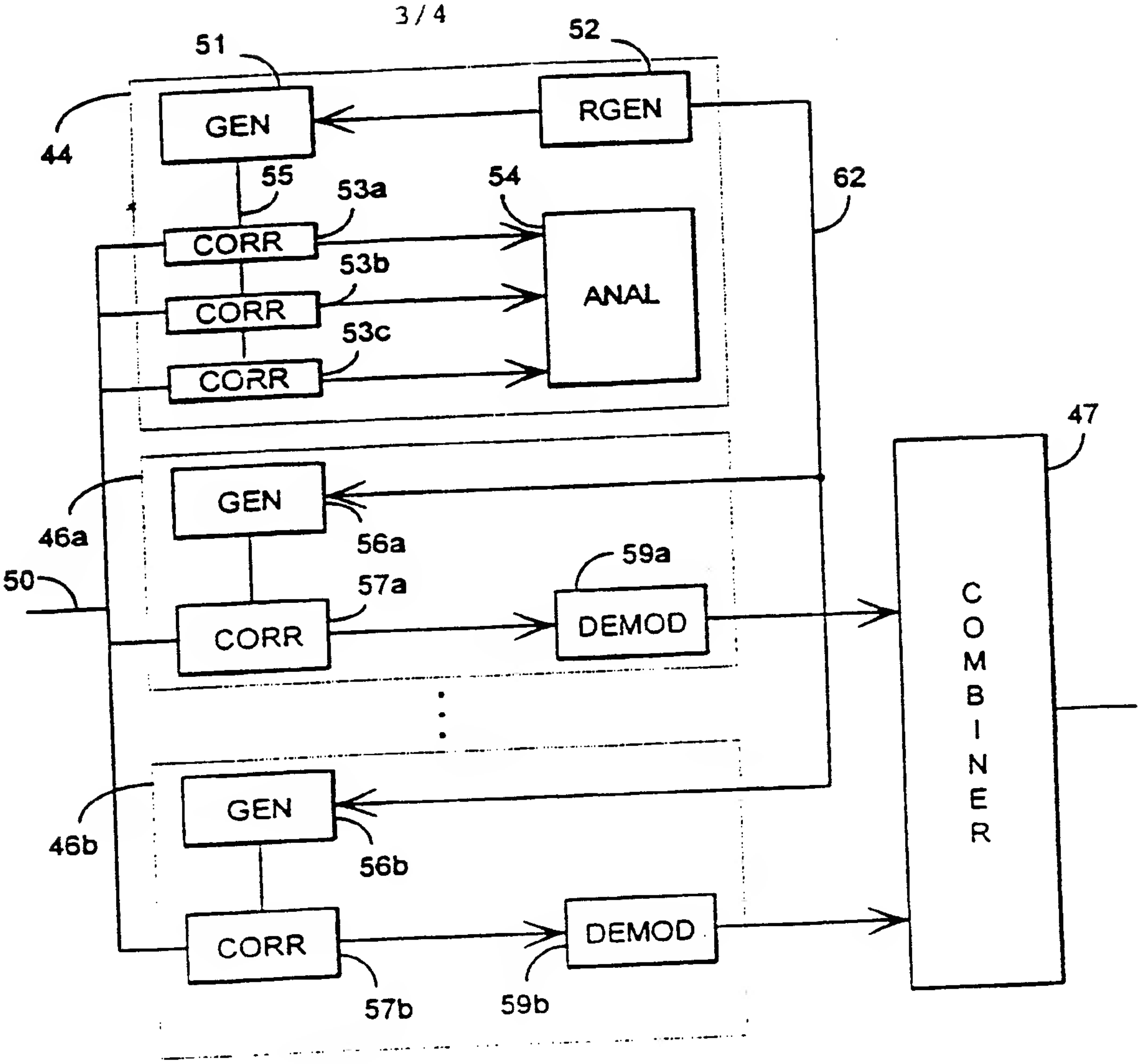
59b

Fig. 5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DEMOD
CORR
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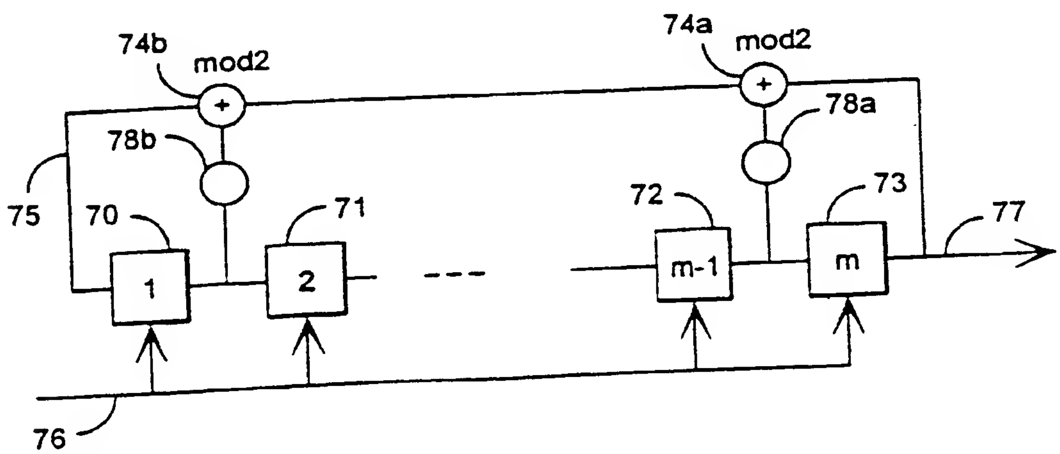
56b
CORR
DEMOD
57b
59b

Fig. 6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m
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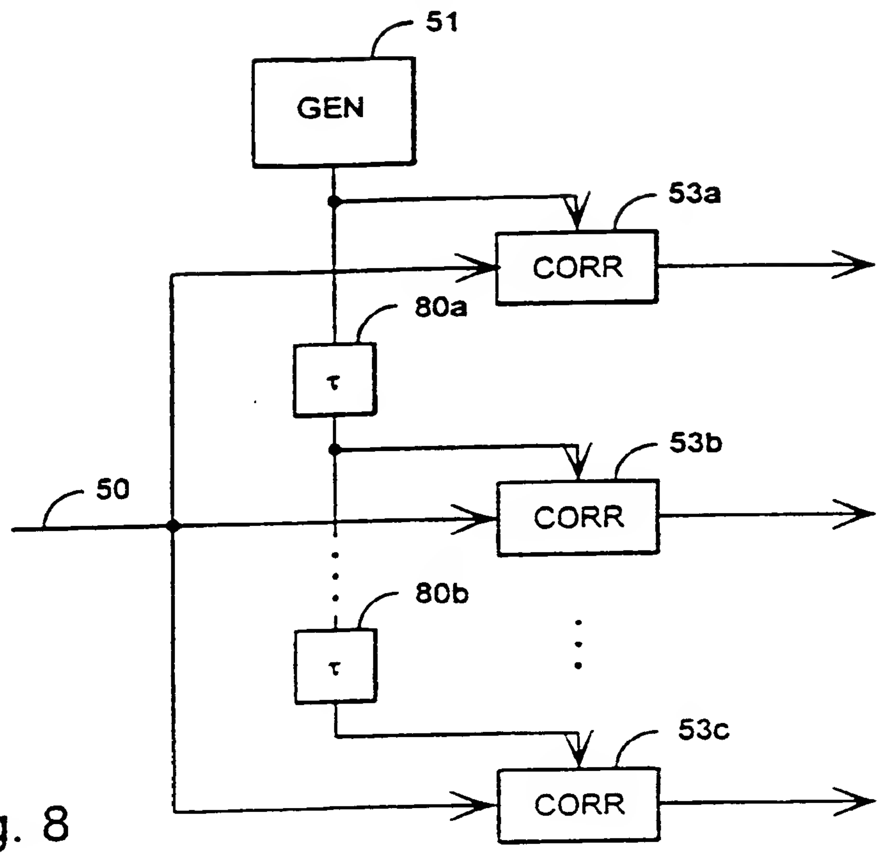
Fig. 7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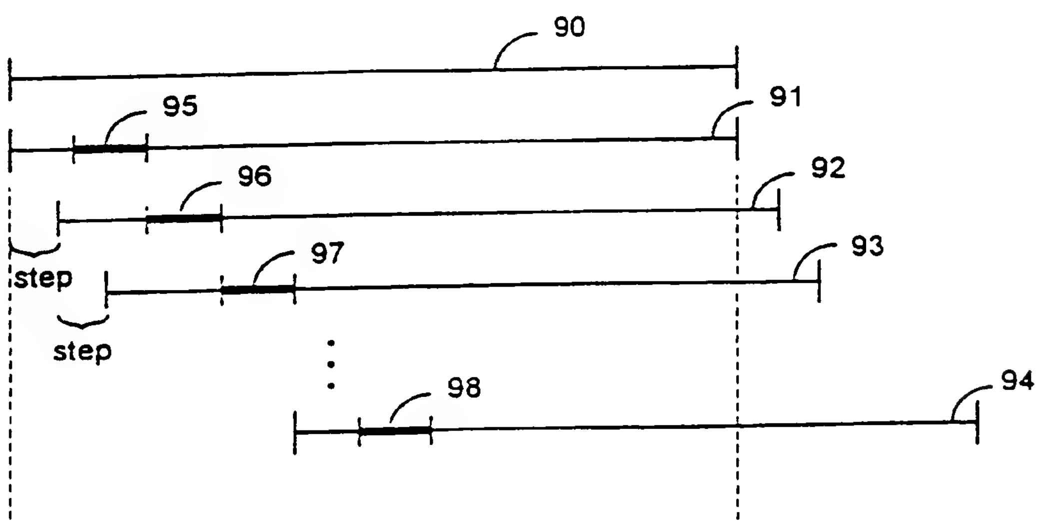
τ
53c
CORR

Fig. 8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step
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step
98
94

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 96/00076

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04B 1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04B, H04L, H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9429985 A1 (MOTOROLA INC.), 22 December 1994 (22.12.94), page 4, line 4 - line 15, abstract --	1-11
A	EP 0622920 A1 (CANON KABUSHIKI KAISHA), 2 November 1994 (02.11.94), abstract --	1-11
P,A	EP 0673130 A1 (NEC CORPORATION), 20 Sept 1995 (20.09.95), column 3, line 28 - column 4, line 31, abstract -- --------	1-11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

3 July 1996

Date of mailing of the international search report

04 -07- 1996

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INTERNATIONAL SEARCH REPORT
Information on patent family members

01/04/96

International application No.
PCT/FI 96/00076

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO-A1-	9429985	22/12/94	NONE	
EP-A1-	0622920	02/11/94	NONE	
EP-A1-	0673130	20/09/95	NONE	